AD/A-007 071

A NEW FORMULA FOR CALCULATING ACOUSTIC PROPAGATION LOSS IN A SURFACE DUCT

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Prepared for:

Defence Research Information Centre

June 1974

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AMENDMENTS

NUMBER	1	2	3	4	5	6	7	8	9	10
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AD/A-007071

DOCUMENT CONTROL SHEET

Overall security classification of sheet ....UNLIMITED........

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1. DRIC Reference (if known)	2. Originator's Reference	3. Agency Reference	4. Report Security Classification
	AUWE TN 511/74 Acc. No 37210		Unlimited

5. Originator's Code (if known)	6. Originator (Corporate Author) Name and Location
012500	Admiralty Underwater Weapons Establishment Portland, Dorset, UK
5a. Sponsoring Agency's Code (if known)	**6a. Sponsoring Agency (Contract Authority) Name and Location**

7. Title

New Formula for calculating Acoustic Propagation Loss in a Surface Duct.

7a. Title in Foreign Language (in the case of translations)

7b. Presented at (for conference papers). Title, place and date of conference

8. Author 1, Surname, initials	9a. Author 2	9b. Authors 3, 4...	10. Date.	pp.	ref.
Baker, W. F.			June 74	10	2
11. Contract Number	**12. Period**	**13. Project**	**14. Other References**		

15. Distribution statement

15. Descriptors (or keywords)

Duct propagation, absorption coefficient.

Abstract

This new formula is derived as an empirical fit to experimental data at 3.25 and 7.5 kHz, embracing limited environmental conditions.

U.D.C. No. 534.21:
534.6

A.U.W.E. Technical Note No. 511/74
June 1974

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ILLUSTRATIONS

DEFINITION OF SYMBOLS USED

A = Absorption Coefficient in dB/kyd.

B = Leakage Coefficient in dB/kyd.

f = Frequency in kHz.

H = Duct depth in feet.

n = Sea State.

R = Range in kiloyards.

t = Temperature (degrees C).

T = Temperature (degrees F).

A NEW FORMULA FOR CALCULATING ACOUSTIC PROPAGATION LOSS IN A SURFACE DUCT

PRÉCIS

1. This note describes the development of a formula for the calculation of the acoustic propagation loss in a surface isothermal duct. The formula derived is an empirical fit to a number of experimental measurements which embrace a limited range of the factors affecting acoustic propagation loss, and extrapolation outside these limits should obviously be regarded with caution. The variation of propagation loss with depth within the duct has not been investigated due to lack of data.

2. Comparison of the measured results with the new formula indicate a mean error of typically less than ± 2 dB, with a standard deviation of 7 dB on individual readings. A total of 438 measured propagation loss values has been used from four different sources.

INTRODUCTION

3. It had been found that the latest version of the formula given by Saxton (Ref. 1) gave duct propagation losses which were greater than the measured values on a number of occasions. For this reason, a systematic study of the differences between measured values and those predicted by the Saxton formula was undertaken.

PROPAGATION LAW

4. Using the symbols already defined, the simplified Saxton duct propagation loss may be written:-

$$\text{Loss (dB)} = 20 \log R + 60 + (A + B) R \qquad \text{for short ranges } (R \leqslant (0.122\ H)^{0.5})$$

or

$$\text{Loss (dB)} = 10 \log R + 5 \log H + 50.9 + (A + B) R \qquad \text{for long ranges } (R > (0.122\ H)^{0.5})$$

5. This note is concerned with the values of the coefficients A and B (Absorption and leakage coefficients).

ABSORPTION COEFFICIENT

6. The coefficient used by Sacton was:-

$$A = \frac{0.28}{T} f^2 \qquad \text{(dB/kyd)}$$

7. In the present formula, a more recent expression derived by Hall (Ref. 2) has been used:-

$$A = \frac{1.776\ f^{1.5}}{32.768 + f^3} + \frac{1}{1 + \frac{32.768}{f^3}} \left(\frac{0.65053\ f_t\ f^2}{f_t^{\ 2} + f^2} + \frac{0.026847\ f^2}{f_t} \right)$$

$$\text{where } f_t = 21.9 \times 10^{\left(\frac{6t + 118}{t + 273}\right)}$$

8. Fig. 1 shows a comparison of these two absorption coefficients over the frequency range 1 to 10 kHz for temperatures of 40°F and 60°F. The new formula is cumbersome to use, but does fit experimental data much more closely than previous formulae.

LEAKAGE COEFFICIENT

9. Saxton's expression for this coefficient has been given in various forms, a commonly used one being

$$B = \frac{K \log f}{173\ (H)^{0.5}} (1.4)^n \qquad \text{(dB/kyd)}$$

where K is an empirical constant whose value has been changed from time to time, a typical value being 1600.

10. Using this expression for the leakage coefficient and the new absorption coefficient, theoretical duct propagation losses were compared with four sets of experimental data, comprising a total of 438 measurements. The main characteristics of the data (range of parameters encountered) are given in Appendix I.

11. For convenience of presentation, the differences between theoretical and measured loss values have been grouped into quasi-logarithmic range classes, and the mean error has been plotted at the mean range of the class (Fig. 2). "Error" is here defined as the measured loss subtracted from the calculated loss.

12. It will be noted that there is an obvious range-dependent component in the mean errors for all four sets of data, and that additionally the errors for the 7.5 kHz data are higher than those for 3.25 kHz and 3.5 kHz.

13. The range-dependent error component indicated that the empirical scaling factor in the coefficient B (= 1400) required modification to obtain a good fit to the data; the frequency-dependent error component suggested that the "log f" factor in the coefficient should be changed. A linear frequency dependence seemed appropriate, since this choice also removes the anomalous effect if the formula is used below 1 kHz.

14. The denominator of the coefficient B was also changed to take into account the slight variation of ray curvature due to temperature, as in the original Saxton expression, but this had little effect compared with the other changes detailed above.

15. As a result of these three changes the final expression chosen for the leakage coefficient is:-

$$B = \frac{26.6\ f}{((1452 + 3.5t)\ H)^{0.5}}\ (1.4)^{n} \qquad \text{(dB/kyd)}$$

16. Fig. 3 shows the mean errors obtained using the new formula, and it is apparent that the formula gives a much better fit to the experimental data. It should be emphasised here that the frequencies used were 3.25, 3.5 and 7.5 kHz, and that the range of environmental conditions is limited as detailed in Appendix I, extrapolation outside the range of conditions considered may invalidate the formula, especially, for instance, with a shallow duct at low frequencies.

REFERENCES

Reference

1. H. L. Saxton, H. R. Baker and N. Shear.
"10-kilocycle Long-Range Search Sonar"
NRL Report 4515, Naval Research Laboratory, Washington. August 1955.
Unclassified.

2. H. R. Hall.
"Values of the New Acoustic Absorption Coefficient of Sea Water"
NUWC TN 63, Naval Undersea Warfare Center, February 1968. Unclassified.

APPENDIX I: SUMMARY OF EXPERIMENTAL DATA

	Data 1	Data 2	Data 3	Data 4
Frequency (kHz)	3.25	3.5	3.5	7.5
Number of Readings	174	15	159	90
Range of Duct Depth (feet)	80 to 220	130	140 to 200	80 to 210
Range of Sea State	2-3 to 4-5	2	3	2-3 to 4-5
Range of Temperature °F	64 to 76	64	59 to 62	65 to 76
Range of Ranges (kyds)	1 to 34	1 to 51	4 to 30	1 to 28

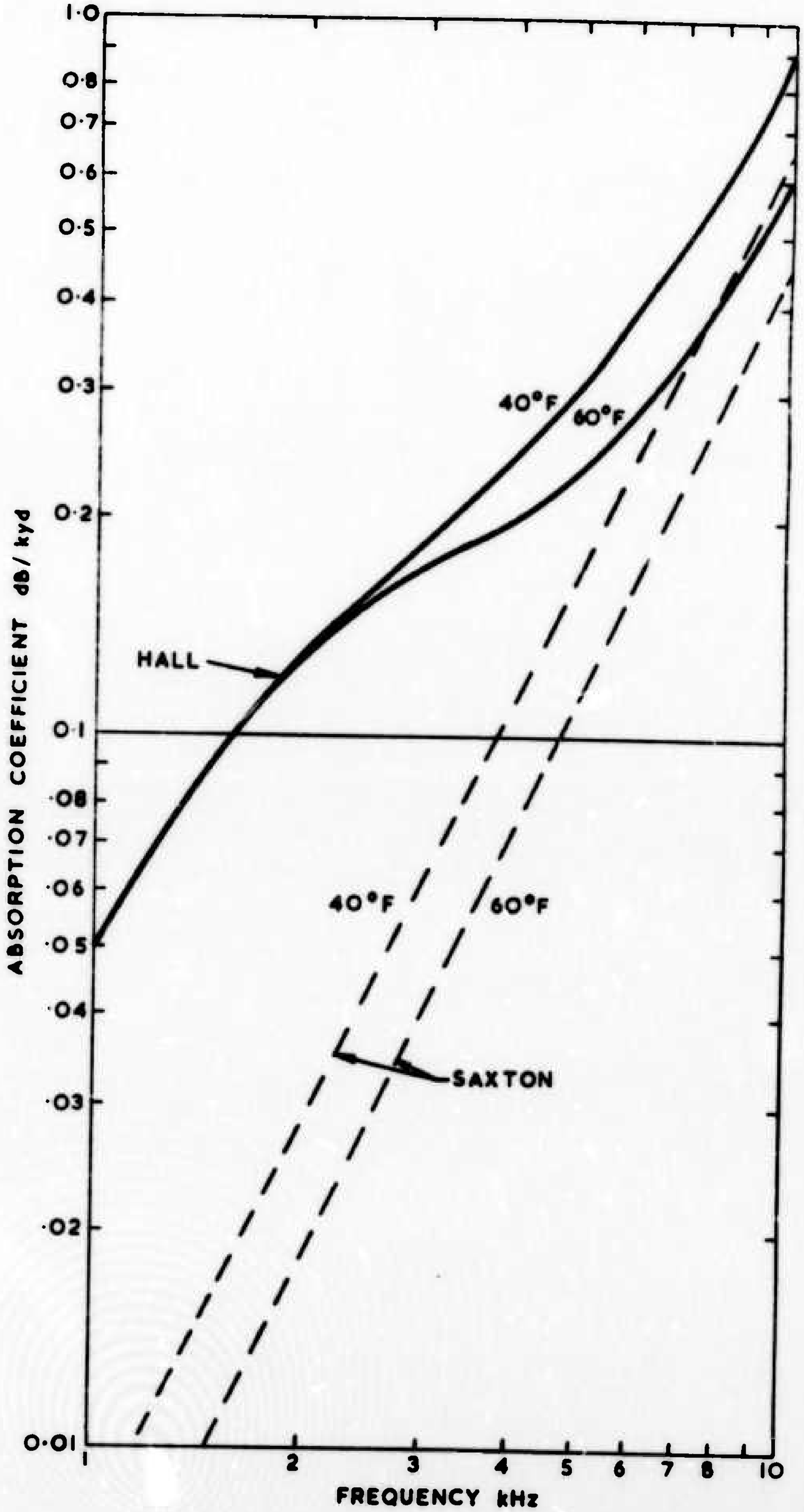


FIG.1. ABSORPTION COEFFICIENT COMPARISON

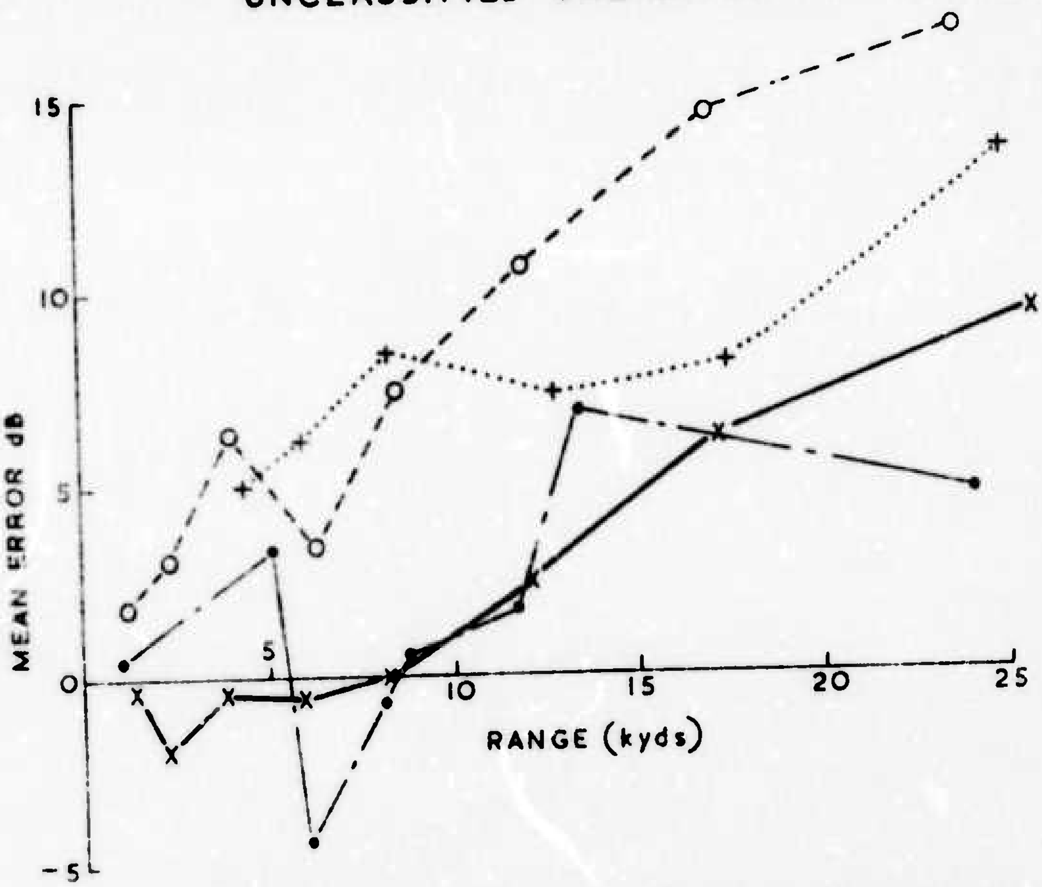
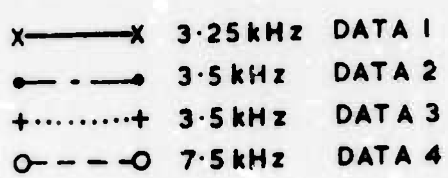


FIG 2. MEAN ERRORS USING SAXTON EQUATION



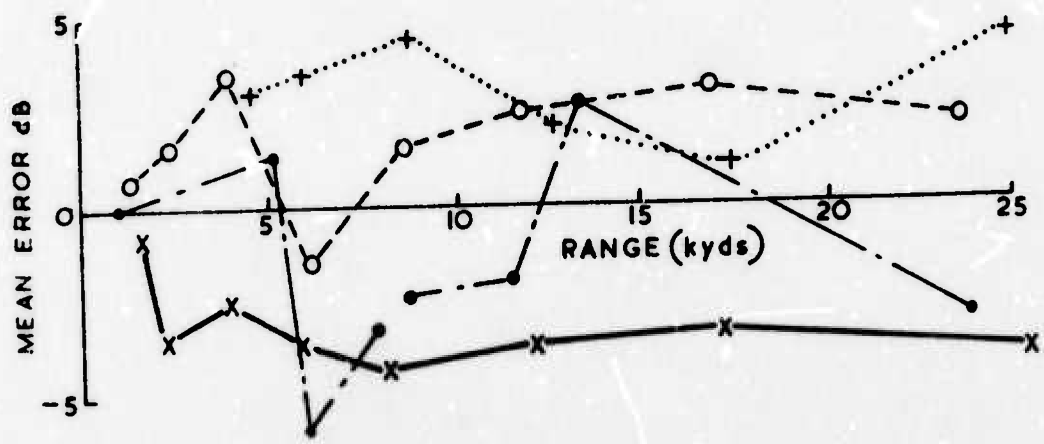


FIG. 3. MEAN ERRORS USING NEW FORMULA